Plastic Electronics

Zhenan Bao*, John Rogers, Kirk Baldwin, Ananth Dodabalapur, Andrew Lovinger, Howard Katz
Bell Laboratories, Lucent technologies
600 Mountain Avenue
Murray Hill, NJ 07974

Organic and polymeric semiconducting materials are of great interest recently because of their potential applications in light emitting diodes, photovoltaic cells, and thin film transistors (TFTs). For low-cost and disposable electronics, such as electronic price tags and simple displays, the development of high performance organic TFTs will be the key element. Organic transistors offer opportunities for low-cost fabrication from solution or low temperature vacuum evaporation. Much progress has been made in recent years in material and fabrication. Some aspects in materials and processing related areas will be discussed.

1. Basics of TFTs

A thin film field-effect transistor (FET) consists of three electrodes, i.e. the gate, drain and source electrodes. When the transistor is in its "off" state (gate voltage equals to zero), the current flow between the drain and source electrode is low. After a gate field is applied, charges can be induced in the semiconducting layer at the dielectric and semiconductor interface. As a result, the current flow between drain and source electrodes is increased because of an increase in the number of charge carriers. Generally, higher gate voltage results in more induced charge carriers and consequently higher current flow. The performance of FETs can be characterized by their field-effect mobilities and on/off ratios. The field-effect mobility describes the average charge carrier drift velocity per unit electric field. The on/off ratio is the ratio between the on-state and the off-state. A high performance FET should have high field-effect mobility and high on/off ratio. For organic FETs, the highest values were realized with pentacene with mobility around 2 cm^2/Vs and more than 10^6 for on/off ratio.

2. Vacuum sublimation

Most of the high performance organic semiconductors discovered so far are small molecular weight materials with high melting temperatures (above 250ºC) and low solubility. They are generally aromatic molecules with extended π-systems or fused ring structures. The most common method for thin film deposition of these materials is by vacuum sublimation. In this method, a boat is heated inside a vacuum chamber and the evaporated organic vapor condenses on the desired substrate to form a thin film. The deposition process can also, in some cases, further enhancing the purity of the evaporated material. Highly ordered polycrystalline films are obtained and this is essential to achieve high field-effect mobilities. Vacuum deposition methods do not involve organic solvents and multilayer films can be deposited without worrying about dissolving previous layers during subsequent depositions. However the drawback is that the process requires a time consuming period to reach the high vacuum state, and is difficult to deposit films over a large area.

3. Solution processing methods

Solution based processing methods, such as spin-coating, casting, and printing, can potentially reduce fabrication cost and lead to large area reel-to-reel production. In particular, printing methods are especially desirable since the deposition and patterning steps can be combined in one single step. The following session summaries several reported processing methods involving solution processable materials.

3.1. Screen-printing

Screen printing prints patterns by squeezing ink through a predefined screen mask using a "doctor blade". It is an additive method, in which lines and spacings as small as 75 μm can be printed. The printing process involves pressing a liquid (ink) using a squeegee through a predefined screen mask and transfer patterns to the substrate. This method has been widely used in commercial printed circuit boards and was recently adopted by several research groups to print electrodes as well as the active polymer layers for organic transistors and simple circuits.

The resolution of screen-printing is limited to above 75 μm and there are also some additional requirements to the ink materials. For example, the ink should be relatively viscous so that it can not go through the screen before a squeegee is applied. Particles are sometimes incorporated into the ink to increase its viscosity. But the particle sizes should be sufficiently small so that they will not clog the screen. Therefore, screen-printing is most suited for relatively large features (greater than 75 μm) and for materials with high viscosity, such as dielectric polymers and conducting polymers and pastes.

3.2. Soft lithography

Soft lithography is a general term that's used to describe high resolution (features less than 25 μm) patterning methods that involve elastomer masks, stamps, and molds. The masks, stamps, and molds are fabricated by casting and curing a prepolymer of polydimethylsiloxane (PDMS) against a patterned photoresist. Many replicas can be generated from a single photoresist pattern, and each can be used many times. Therefore, once a stamp or mold is made, it can be used to pattern metal films or mold liquid materials without using additional photolithography. It is potentially low-cost and may have the possibility of patterning over a large area in a reel-to-reel fashion.

4. Summary and future directions

Processing methods for fabrication of organic thin film field-effect transistors are surveyed. Vacuum evaporation method for insoluble oligomers and printing techniques for solution processable materials are discussed. Up to date, all the devices are demonstrated only in laboratory scales. The possibility of producing them in a manufacturing setting has yet to be addressed. It is likely that several processing methods have to be used concurrently depending on their capability to handle different kind of materials and feature sizes.